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Measuring H_0 from the 6dF Galaxy Survey and future low-redshift surveys

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Abstract. Baryon acoustic oscillations (BAO) at low redshift provide a precise and largely model-independent way to measure the Hubble constant, H_0. The 6dF Galaxy Survey measurement of the BAO scale gives a value of $H_0 = 67 \pm 3.2$ km s^{-1} Mpc^{-1}, achieving a 1σ precision of 5%. With improved analysis techniques, the planned WALLABY (HI) and TAIPAN (optical) redshift surveys are predicted to measure H_0 to 1–3% precision.

Keywords. cosmology: observations, surveys, distance scale, large-scale structure of universe

1. Introduction

Baryon acoustic oscillations (BAO) produced by the interaction of photons and baryons in the early universe provide an absolute standard rod that is calibrated by observations of the cosmic microwave background (CMB). The BAO scale is determined by well-understood linear physics and depends only on the physical densities of dark matter and baryons. In principle, the BAO scale can be measured to about 1% precision from tracers of the large-scale structure of the universe over a wide range of redshifts. It is therefore a powerful probe of cosmic geometry (Seo & Eisenstein 2003; Blake & Glazebrook 2003), particularly as it can be used to measure the evolution of both the Hubble parameter $H(z)$ radially along the line of sight and the angular diameter distance $D_A(z)$ tangentially across the line of sight. However to achieve the full precision possible from the BAO scale requires large samples of tracers ($\sim 10^6$ objects) over large volumes ($\sim 1\,\mathrm{Gpc}^3$).

BAO are complementary to other probes of the universe's geometry, such as supernova measurements of luminosity distance $D_L(z)$, in that they measure different cosmological properties and have a different physical basis (and therefore have different sources of systematic errors). The main potential sources of systematic errors for BAO measurements are non-linear clustering, redshift-space distortions and possible scale-dependent bias.

At low redshift, BAO yield a measurement of the distance scale that requires only the CMB calibration of the sound horizon scale and is largely independent of the details of the cosmological model (Beutler *et al.* 2011). Thus a measurement of the BAO scale in a low-redshift ($\bar{z} \approx 0.05$) galaxy survey like the 6dF Galaxy Survey (6dFGS) yields a direct and nearly model-independent measurement of the Hubble constant H_0.

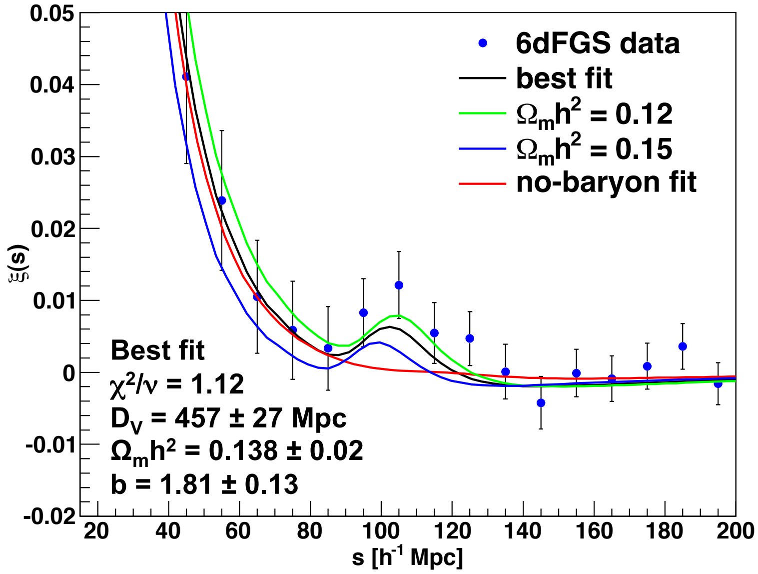

Figure 1. The BAO signal in the 6dFGS correlation function. The measured correlation function and errors are shown as blue dots with errorbars. The best-fit model (black curve) is also shown, along with two flanking models (blue and green curves) and the best-fit no-baryon model (red curve). The parameters of the best-fit model are given in the legend at lower left.

2. The 6dF Galaxy Survey

The 6dF Galaxy Survey (6dFGS) is a redshift and peculiar velocity survey of the southern sky (Jones *et al.* 2004, 2006, 2009). It used the 6dF multi-fibre spectrograph on the UK Schmidt Telescope (UKST) operated by the Australian Astronomical Observatory (AAO) to spectroscopically survey a sample of near-infrared galaxies selected from the 2MASS Extragalactic Source Catalog (XSC; Jarrett *et al.* 2000) covering the whole southern sky outside of 10° from the Galactic plane. The 6dFGS measured redshifts for more than 125000 galaxies with $K \leqslant 12.65$ and Fundamental Plane peculiar velocities for about 9000 early-type galaxies. The results discussed here are based on the 6dFGS redshift survey, for which the median redshift is $z = 0.052$.

For the purpose of measuring the correlation function, galaxies were excluded from the sample if they lay in sky regions with completeness <60%. This reduced the sample to 75117 galaxies. The selection function was derived by scaling the survey completeness as a function of magnitude to match the integrated on-sky completeness using mean galaxy counts. The effective weighted volume of the sample is $0.08\,h^{-3}\,\mathrm{Gpc}^3$, and the effective redshift at which the BAO scale is measured is $z_{\rm eff} = 0.106$.

3. The galaxy correlation function and H_0

Figure 1 shows the correlation function for this sample of galaxies computed using the Landy & Szalay 1993 method with inverse density weighting following Feldman, Kaiser & Peacock 1994 and an integral constraint correction. The errorbars on the correlation function points are based on log-normal realisations. Full details of the methodology are given in Beutler *et al.* 2011. The BAO peak in the correlation function at a scale of $105\,h^{-1}\,\mathrm{Mpc}$ is clearly visible.

The correlation function is modelled accounting for the wide-angle effects in this large-area survey, the effects of non-linear evolution in the galaxy clustering, and the scale-

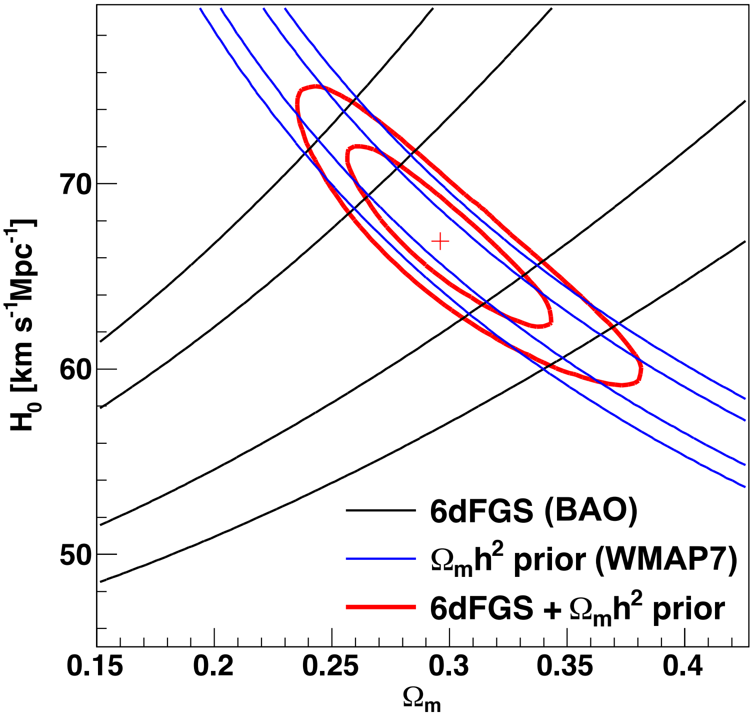

Figure 2. The constraints on H_0 and Ω_m from the 6dFGS BAO measurement (black contours), the WMAP7 CMB observations (blue) and the BAO and CMB measurements combined (red).

dependence of the bias; again, details are given in Beutler *et al.* 2011. The 6dFGS sample is not large enough to constrain $H(z_{\rm eff})$ and $D_A(z_{\rm eff})$ separately using the 2D correlation function; instead we constrain the combined quantity $D_V(z_{\rm eff})$ (Eisenstein *et al.* 2005) using the 1D correlation function.

The model for the correlation function uses parameter values from WMAP7 (Komatsu *et al.* 2010) to define the power spectrum and the BAO scale. We fit the correlation function over the range $10\,h^{-1}\,$Mpc to $190\,h^{-1}\,$Mpc. The free parameters in our model are the physical matter density $\Omega_m h^2$, the bias b, the non-linear damping scale k_*, and the scale distortion parameter $\alpha = D_v(z_{\rm eff})/D_v^{\rm fid}(z_{\rm eff})$ that measures the deviation of the BAO scale from the fiducial cosmological model.

Our best-fit model for the correlation function is shown in Figure 1 and has parameters $\Omega_m h^2 = 0.135 \pm 0.020$, $b = 1.65 \pm 0.10$, $k_* > 0.19\,h\,{\rm Mpc}^{-1}$ (95% confidence lower limit), and $\alpha = 1.039 \pm 0.062$. This corresponds to $D_V(z_{\rm eff}) = 457 \pm 27$ Mpc, with a precision of 5.9%. Marginalising over k_* and using a prior on $\Omega_m h^2$ from WMAP7, we obtain a measurement for the Hubble constant of $H_0 = 67 \pm 3.2\,{\rm km\,s^{-1}\,Mpc^{-1}}$, which has an uncertainty of 4.8%. The corresponding estimate for Ω_m is 0.296 ± 0.028. The joint constraints on H_0 and Ω_m are shown in Figure 2.

The 6dFGS result for H_0 (Beutler *et al.* 2011) has comparable precision to that published recently from the SH0ES distance-ladder program (Riess *et al.* 2011), $H_0 = 73.8 \pm 2.4\,{\rm km\,s^{-1}\,Mpc^{-1}}$, although our result is 1.7σ lower. It is similarly comparable to, and in better agreement with, the model-dependent WMAP7 estimate (Komatsu *et al.* 2010), $H_0 = 70.3 \pm 2.5\,{\rm km\,s^{-1}\,Mpc^{-1}}$. The advantages of the 6dFGS result are that it is not reliant on a series of distance ladder steps (unlike the SH0ES result) and that it is largely independent of the cosmological model (unlike the WMAP7 result).

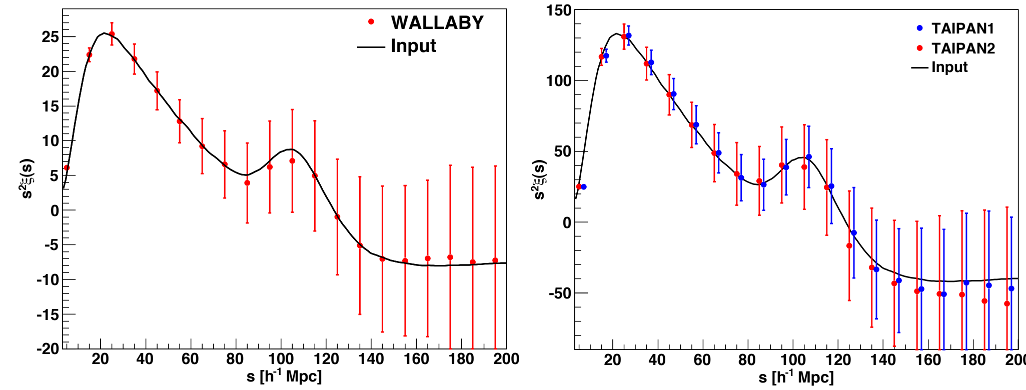

Figure 3. Predicted BAO signals and uncertainties in the galaxy correlation function from the WALLABY HI survey with ASKAP (left) and the TAIPAN survey with UKST (right).

4. Constraints on H_0 from future surveys

How precise could future H_0 measurements from low-redshift galaxy surveys be? Two large low-z galaxy surveys are in prospect: the WALLABY HI survey (Duffy *et al.* 2012) planned for the Australian SKA Pathfinder and the TAIPAN optical survey planned for the UKST (Beutler *et al.* 2011). WALLABY is expected to start in 2014–15. It will cover the entire sky (with a matching Westerbork survey) and give redshifts for $\sim 6\times 10^5$ galaxies with $b \approx 0.7$ and $\bar{z} \approx 0.04$ over a volume $V_{\rm eff} \approx 0.12\,h^{-3}\,{\rm Gpc}^3$. TAIPAN is a southern-sky survey expected to start in 2015. It will (at a limit of $r < 17$) give redshifts for $\sim 4\times 10^5$ galaxies with $b \approx 1.6$ and $\bar{z} \approx 0.07$ over a volume $V_{\rm eff} \approx 0.23\,h^{-3}\,{\rm Gpc}^3$.

Figure 3 shows the predicted BAO signal in the correlation functions for both these surveys, based on 100 log-normal realisations. We find that WALLABY obtains essentially the same precision in measuring H_0 as 6dFGS. However the deeper TAIPAN survey, with its larger effective volume and higher bias, can measure H_0 with 3% precision. In addition, density field reconstruction has shown significant improvement in the cosmological parameter constraints by using extra information from the density field (Padmanabhan *et al.* 2012). At low redshift this gives an improvement of about a factor of two, so could improve the precision of the H_0 measurement for 6dFGS and WALLABY to $\sim$2.5% and for TAIPAN to $\sim$1.5%. A combined analysis using both the low-bias WALLABY galaxies and the high-bias TAIPAN galaxies could do even better.

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